LIGHT AND HEALTH IN FACTORY WORK PLACES

Vandahl, C.[1], Bieske, K.[1], Wolf, S.[1], Schierz, Ch.[1]
[1] TU Ilmenau, FG Lichttechnik, Ilmenau, Germany
cornelia.vandahl@tu-ilmenau.de

Abstract

Current standards and guidelines are directed mainly towards visual performance and visual comfort. Biological non-visual effects are not included, although they are well-known for many years. We know that a good illumination increases not only the performance, but also well-being and activity of people.

Light influences important biological functions in human, namely melatonin suppression at night, delay or advance of the circadian rhythm, stabilisation of the circadian rhythm and increase of alertness.

In activation lies a high potential for illumination practice. Unfortunately this effect is hardly investigated for daytime use. At the TU Ilmenau a study is in progress dealing with biological light effects at workplaces in factory buildings.

Keywords: Biological effects of light, industrial lighting

1 Introduction

Light influences important biological functions in human, namely melatonin suppression at night, delay or advance of the circadian rhythm, stabilisation of the circadian rhythm and increase of alertness. New findings show these effects for illuminance levels above 90…180 lx (vertical illuminance at the eye). Higher levels result in increases effects. In dark factory buildings, where illuminance levels in this range are likely to be found, more illuminance at the eye could increase activity, alertness and well-being.

Biological effects increase with the use of light that is enriched in the blue spectral range to which the circadian system is most sensitive. The effect also depends on spatial distribution and size of the light sources. Inferior retinal light exposure is more effective than superior retinal exposure. Large area luminaires are also more effective than point sources. Probably dynamic light can cause even more effects.

In activation lies a high potential for illumination practice. Unfortunately this effect is hardly investigated for daytime use. There are many studies for shift work use. Also the stabilisation of the circadian rhythm can be important. However, it is not known, how to implement these findings at workstations reasonably.

Nevertheless, it has not been investigated yet which quantity of light reaches the eye during work. This quantity depends on the lighting system and the reflectance properties of the environment as well as on the movement of the head. In a laboratory pre-test the illuminance level at the eye has been measured.

2 Laboratory measurement of the illuminance level at the eye

The biological effect of illumination depends on light quantity, spectral distribution and spatial distribution. For quantification of effects, all these parameters have to be measured. Because this is a very complex task, usually only the vertical illuminance near the eye is being measured, while the line of sight and the motion of the head are ignored. For this reason, a system called “LuxBlick” has been developed which measures the illuminance at the actual eye position. Therefore a sensor is fixed at an eyeglasses’ frame (Figure 2).

2.1 Measurement System

The measuring system is a further development of the system presented in (Hubalek, 2006). It is capable to measure illuminance and blue-light irradiance during several days with a temporal resolution of one second and to save these measured values continuously. Based on this system the interrelationship between these values and parameters of well-being shall be investigated. The requirements on the measured value acquisition can be summarized as follows:

- The device shall be wearable in everyday life.
- It must be battery-supplied with an operation period of at least one week.
- The data recording shall be made over several weeks with no data loss during power failures (e.g. battery replacement).The measured values must have absolute time-stamps.

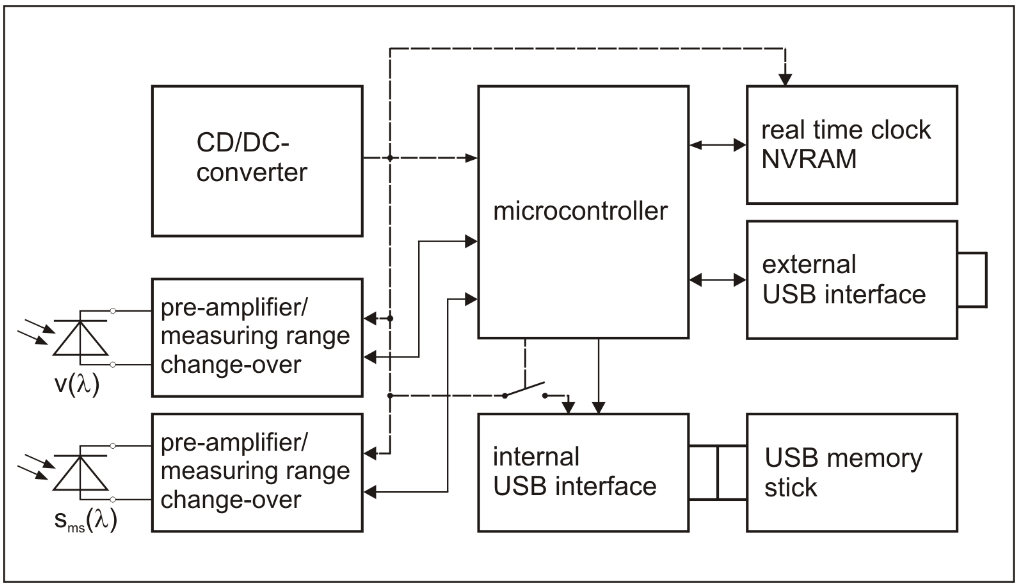

Figure 1. Block diagram of the measurement system "LuxBlick"

Figure 1 shows a block diagram of the implemented device. Central part is a microcontroller Atmel ATmega644P controlling all workflows, containing the necessary analog digital converter and putting temporarily the measured values in a non-volatile memory (NVRAM) located in the real-time clock. This real-time clock also ensures absolute time-stamps for the measured data and generates every second an impulse triggering a new measurement. The size of the NVRAM is sufficiently large to save the measured data captured during approximately 7 minutes, afterwards these data must be transferred to USB-memory.

The intermediate storage of data in the NVRAM is performed because of the power consumption of the USB-memory and of the required internal USB-interface. When both parts would be constantly powered on, the two NiMH-cells supplying the whole device would be empty after few hours. Consequently the data memory with the associated interface is normally currentless and will only be switched on whenever the NVRAM is filled with approximately 80 % of its capacity to transfer the measured values. For the data memory a commercially available USB memory stick is used in which data captured during several months can be stored per gigabyte of size.

The pre-amplifiers convert the photocurrent generated in the photo sensors to a voltage filtered by a low pass. Furthermore each pre-amplifier is equipped with several measuring ranges which can be selected by the microcontroller. The voltage created in this way is transformed by the analog digital converter contained in the microcontroller. The usable metering range runs from 1,0 lx to 40 000 lx.

Figure 2. Measurement system "LuxBlic"

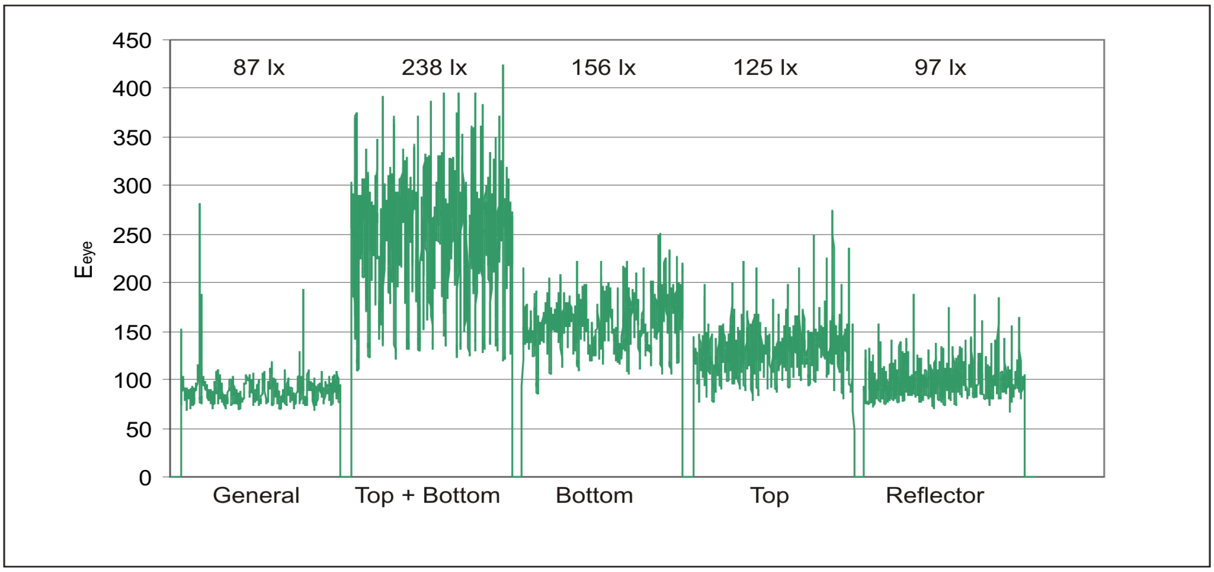

Figure 3. Example for a measurement with LuxBlick system

2.2 Test work place

In the laboratory, a test work place was installed. Test persons carried out installation work for 10 minutes while wearing the sensor-equipped eyeglasses' frame (Figure 2). Various illumination systems have been measured (general lighting, vertical luminaires with various sizes and positions (Table 1, Figure 4, Figure 5)). The measured values have been averaged. The vertical illuminance varied between 60 % (general illumination) and 160 % (large scaled luminaire in front of the test person) of horizontal illuminance (Figure 6). The measured illuminance at the actual eye position showed to be only 30 % to 40 % of the vertical illuminance near the eye (Figure 7).

For biological effects a illuminance at the eye caused by large-scale luminaires is important. In the test the lower luminaire and the right and left mounted luminaires produced the same illuminance levels at the eye (Figure 6). Therefore the luminaire position at workstations can vary. This is expedient for installations in the field studiy.

The vertical luminaires had a luminance of 1 000 cd/m^2. Glare ratings assessed an admissible luminance of 1 500 cd/m^2.

Table 1. Dimensions of the Luminaires

	Top + Bottom	Bottom	Top	Reflector	Right	Left	Right+ Left
Width	1,30 m	1,30 m	1,30 m	1,40 m	0,40 m	0,40 m	2 x 0,40 m
Hight	1,30 m	0,65 m	0,65 m	0,57 m	0,58 m	0,58 m	0,58 m
Distance to the eye	2,00 m	2,00 m	2,00 m	2,00 m	0,80 m	0,80 m	0,80 m

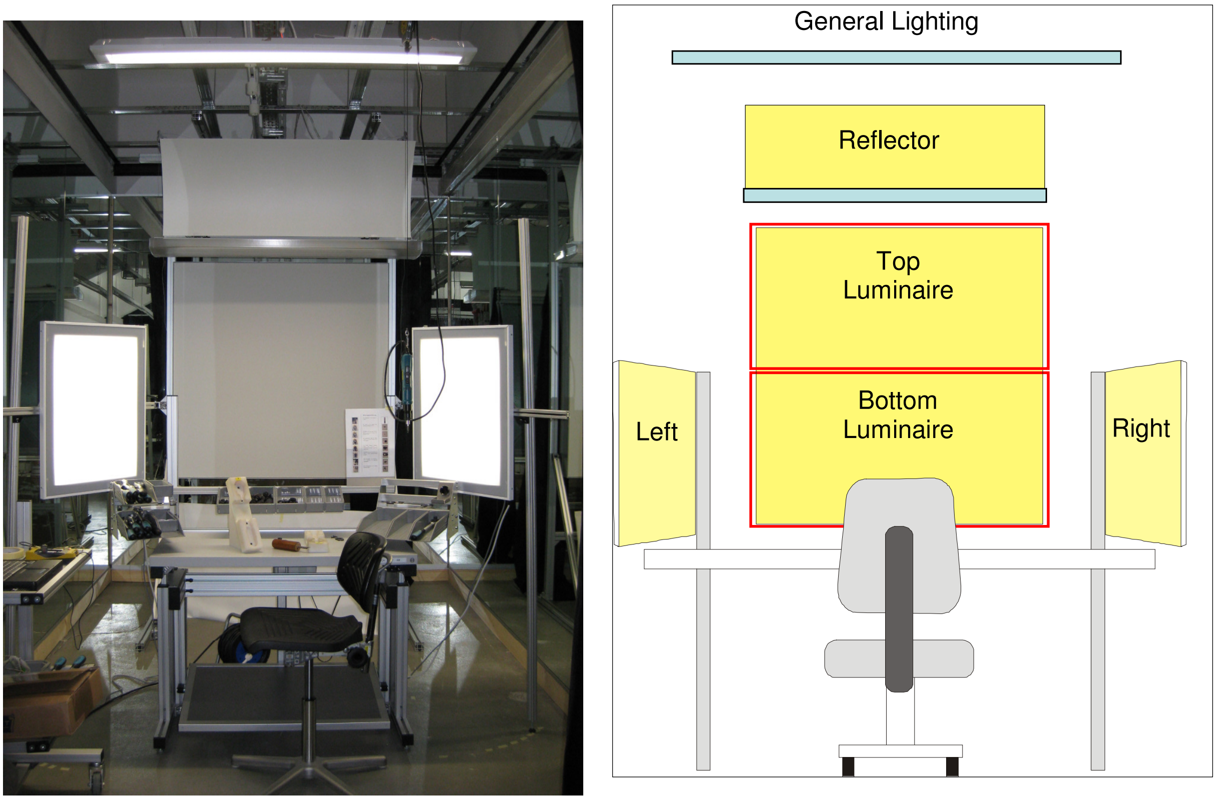

Figure 4. Positions of the Luminaires

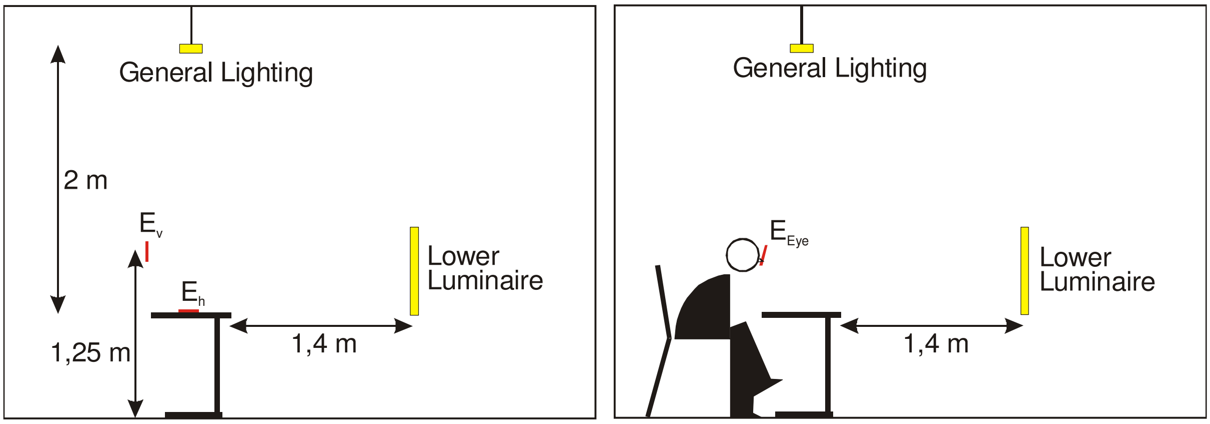

Figure 5. Position of the metering points

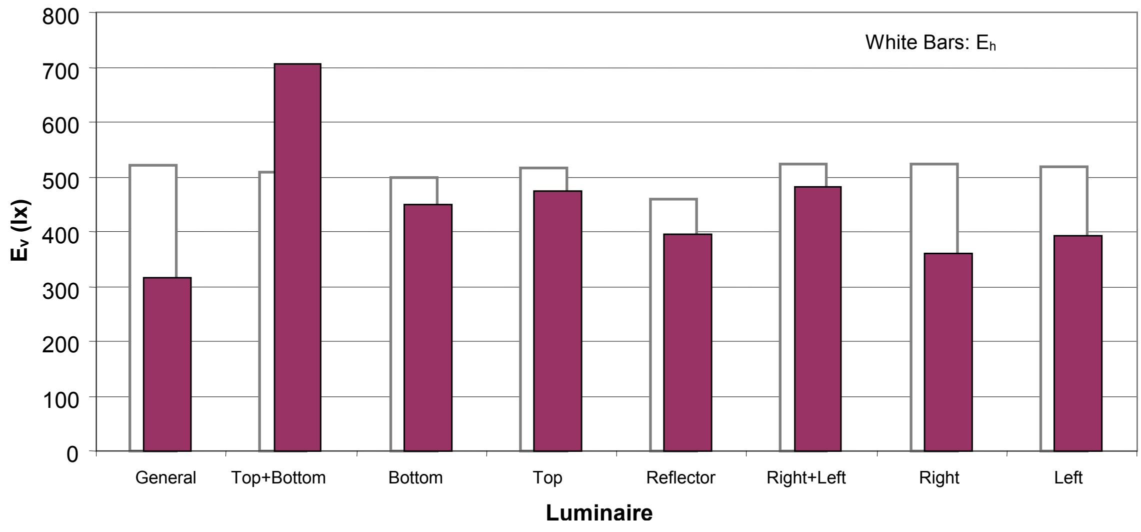

Figure 6. Vertical illuminance E_v near the eye

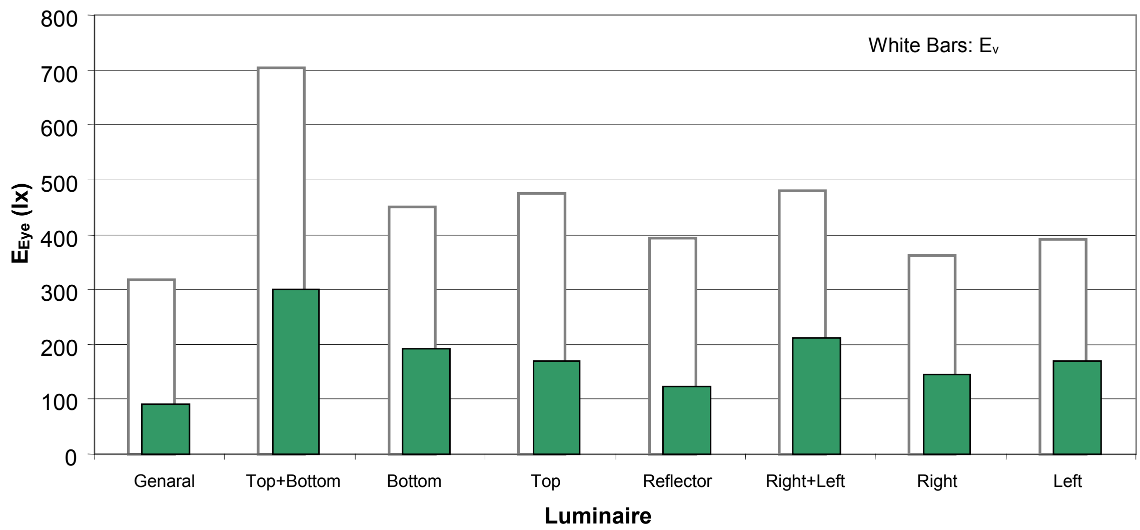

Figure 7. Illuminance E_{Eye} at the eye

3 Field study in factory buildings

Based on the results of the laboratory tests, 40 workstations in factory buildings have been set up with vertical large-scale luminaires. The rooms have dark walls and little daylight. The vertical luminaires have a luminance of 1 500 cd/m^2 and are installed in front of the user. Consequently the number of vertical bright areas has been increased. The colour temperature of the luminaires can be varied between 3 000 K and 8 000 K.

Every situation was being tested for 4 weeks. The test persons rated well-being, activity, sleep quality and light quality. Correlations between light situations and peoples' ratings are expected. Therefore, illumination parameters as well as blue-light weighted values for each light situation were evaluated. Figure 8 exemplifies a work station, in table 3 and 4 the metering data are presented.

Table 2. Situations in the field study

Situation	General lighting	Additional vertical large-scale luminaires
S1	Current situation 3 000 – 4 000 K	--
S2	Current situation 3 000 – 4 000 K	8 000 K
S3	Current situation 3 000 – 4 000 K	luminaires change the colour temperature from 8 000 K to 3 000 K during a working day
S4	Current situation with 8 000 K lamps	

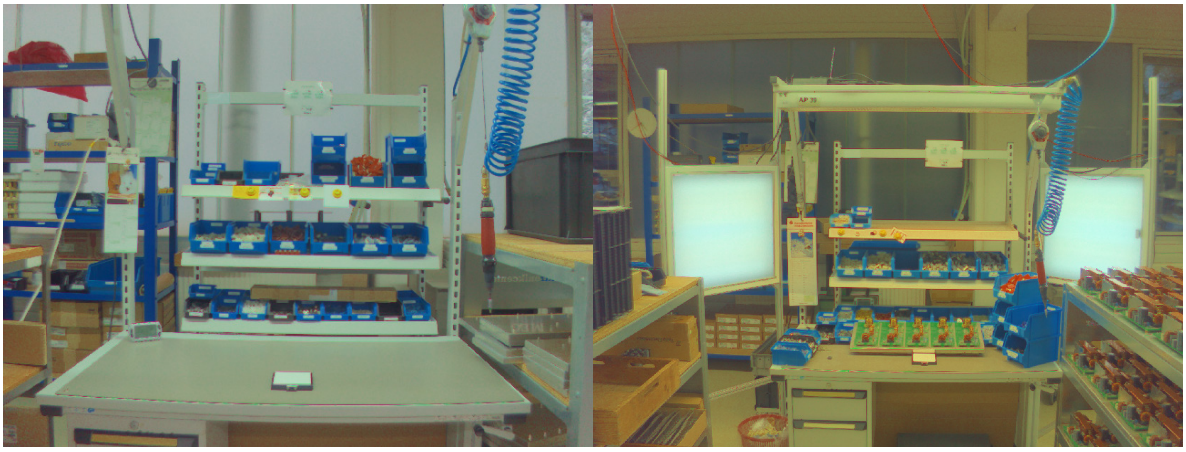

Figure 8. Example for a workstation (left: S4, right: S2)

Table 3. Illuminance at the eye (example figure 8) measured by LuxBlick system (mean and standard deviation)

Situation	S1	S2	S3	S4
E_{eye} (lx)	129,8 ± 26,6	378,5 ± 82,2	311,4 ± 84,6	304,9 ± 47,9
E_{ms} at the eye (mW/m^2)$_{eff}$	80,2 ± 7,4	254,5 ± 72,0	159,4 ± 44,86 .... … 254,5 ± 72,0	252,8 ± 47,7

Table 4. Horizontal and vertical illuminance at the desk (example figure 8)

Situation	S1	S2	S3	S4
E_h (lx)	2 007,3	2 187,5	2 223,8	2 163,9
E_v (lx)	873,7	1 120,0	1 145,4	991,0

Table 5. Illumination and colour temperature at all workstations (mean and standard deviation)

Situation	S1	S2	S3	S4
E_h (lx)	1 010 ± 570	1 120 ± 550	1 040 ± 560	1 185 ± 700
E_v (lx)	360 ± 300	575 ± 360	490 ± 295	405 ± 320
Colour temperature (K)	4 000	4 200	3 900	6 300

Table 3 and table 4 show the metering data of an investigated working station. The positions of the metering points correspond to figure 5. E_{ms} is the irradiance weighted with relative spectral responsivity curve $s_{ms}(\lambda)$ for suppression of melatonin (DIN, 2009). This example shows the increase of illumination level at the eye in situation S2 and S3 by additional luminaires. Changes in daylight level, task pattern or arrangement of material around the work station influence the metering data remarkable.

Table 5 shows the mean of the metering data of all investigated working stations.

Contrary to the expectations the test series are not completed until deadline. Therefore the results will be presented with additional information at the poster.

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